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REVIEW OF 1949 SOVIET PERIODICAL LITERATURE ON GEOPHYSICAL PROSPECTING

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Soviet research in geophysical prospecting includes electrical, seismic, gravitational, and thermal methods with emphasis on the first two, according to articles published in Soviet periodical literature.

Electrical Methods

According to a report by Enenshteyn and Aronov (1), a field method for studying electric fields in the earth was worked out in theory by A. N. Tikhonov in the Geophysics Institute, Academy of Sciences USSR. This method, according to the authors, demanded new instruments as well as new techniques in field study. The method developed is described as follows: A transmitting dipole consisting of the usual electrical prospecting cable (PSM) and two electrode grounds is series connected with a thyratron generator which sends square wave pulses into the ground through the transmitting dipole. A short-wave transmitter with antenna is connected synchronously with the thyratron generator. The thyratron generator and the short-wave transmitter may operate simultaneously or with time lag as required. The electric field created by the current pulse is received by the receiving dipole, which can be placed at various distances from the transmitting dipole.

The receiving dipole consists of a PSM cable, one end of which is grounded through the usual low-ohmic resistance, while the other end is connected to the grid of an input amplifier tube through a high-frequency filter. The second electrode of the receiving dipole is the common ground for the entire receiving unit. The resistance of the second electrode ground is very great, since it is actually the leakage resistance of the grid of the input amplifier tube (500,000 ohms). A filter is used to prevent interference from broadcast stations. The amplifier output is applied directly to the vertical plates

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of the cathode-ray oscilloscope. Since only a single pulse is to be received, there is only one horizontal sweep, which must begin at exactly the same time that the signal is received on the vertical plates.

In order to be sure that the signal received is shown completely on the screen of the oscilloscope, the horizontal sweep should be started a fraction of a second before the arrival of the pulse from the earth. This is accomplished by having a receiver at the receiving point tuned to the frequency of the short-wave transmitter at the transmitting dipole location. The output from this receiver is applied to the delayed sweep circuit which is in turn connected to the horizontal plates of the oscilloscope. The signal received is amplified several volts by the receiver and causes the single horizontal delayed sweep of the cathode-ray oscilloscope to operate. The equipment used in the transmitting unit (thyratron generator, TG-8-3000; short-wave transmitter; four 6L6s, two in push-pull) and in the receiving unit (filter, wide-band amplifier, three 1851s, cathode-ray oscilloscope, short-wave receiver, and delayed sweep circuit) is described in detail.

A second report on Enenshteyn's method deals with experiments on transmitting and receiving dipoles(2). Duplication of much of the material in (1) is noted. The author shows that the reflected current and voltage waves arising in a closed circuit do not materially distort the form of the square-wave pulse in the transmitting dipole.

In Lipskaya's theoretical study (3) of the behavior of electric fields excited in the earth when it contains an inclusion of properties differing, particularly in conductivity, from the surrounding medium, the earth is assumed to be isotropic and homogeneous and the foreign body, spherical, and the depth at which the body is buried is in no way limited. The solutions obtained, she asserts, can be applied to charged-body studies, electroprofiling over a bounded foreign body, and electrocarrotage (core sampling); with certain changes, the same theory can be applied to problems connected with the use of extended or line electrodes (the method of equipotential lines etc.).

In a subsequent work (4), Lipskaya compares quantitatively the exact solution obtained in the previous work with the approximate expression generally used in electrical prospecting work for the anomalous field. A summary of Lipskaya's comparison follows: In practice, the influence of the earth's surface is approximated by simply doubling the anomalous field found for an unbounded medium. This approach is admissible in problems where the earth-atmosphere system can be replaced by an earth-earth system constructed symmetrically with respect to a flat ground surface. Only an approximate solution is obtained by this method, since doubling the anomalous field to describe the action of both symmetrical nonhomogenities in the upper and lower half-spaces neglects the interaction of these two elements. The approximate solution provides sufficient accuracy for deeply-buried foreign bodies but inaccurate results for shallow submersions, i.e., for short distances between the symmetrical nonhomogeneities in the earth-earth system. This error has never been evaluated. In the special case for a spherical inclusion having infinitely great conductivity, an accurate solution can be found by two independent methods, namely the method of bi-polar coordinates used in (3) and the method of consecutive electrical reflections. The first approximation of the method of electrical reflections is actually the approximate solution used in practice. The difference between the first approximation and the accurate solution is greater than is usually assumed.

An application of an electrical prospecting method to engineering geology is discussed in another article(5). The author, A. M. Gorelik, discusses the problem of determining the speed and direction of flow of underground waters, which arises quite frequently in engineering-geological surveys, as follows: The first part of the problem is usually solved by using dyestuffs or Slichter

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measurements and the second, by constructing "hydroisohyps." Both these methods, however, require a great deal of drilling work, which slows the study and makes it more expensive. A more economical solution can be obtained by using the charged-body method used in electrical prospecting. In this method, a hole is drilled to the water-bearing seam, a feeder electrode is lowered, and an electrolyte poured in the hole. The speed of displacement of the center of the equipotential lines, equal to the speed of flow, is recorded on the surface. The electrolyte is usually poured in the hole at the beginning of the test; more accurate determinations can be obtained if the electrolyte is poured in the hole periodically in order to maintain high electrolyte concentrations around the feeder electrode (in the usual method, part of the electrolyte is carried away by the flow).

A report by Imyanitov (6) deals with the instruments used in electrical prospecting. Imyanitov notes that a great deal of literature has appeared recently describing instruments -- all based on the principle of the electrostatic generator -- which are used to measure various quantities such as field intensity, voltage, current, and charge. Various authors, he states, use different titles for them, such as "capacitance commutator," "dynamic electrometer," "rotary voltmeter," etc. Imyanitov attempts to generalize the characteristics of this class of instruments. The measurements in the article were made with an instrument, designed by the author, having maximum sensitivity of 0.01 volt per centimeter per division, area of measuring plates 225 square centimeters, and minimum input resistance of 15 megohms.

Seismic Methods

Experiments in modeling seismic-wave phenomena, Riznichenko (7) reports, were initiated in 1944-45 at the Seismic Laboratory of the Geophysics Institute, Academy of Sciences USSR. In the experiments, a mechanical system, i.e., a plane elastic network made up of rubber bands with small weights (lumped masses) fastened in knots, was used as the first model of a solid elastic medium. The size of the weights could be varied in different parts of the network and thus various forms of nonhomogeneities could be obtained in this "discrete" medium. Two quasi-homogeneous layers, for example, with a surface of separation of arbitrary form could be imitated. A special tapper was used on any single weight to set up elastic waves in the network. The motion of any other weight could be recorded by a circuit employing a photoelement, amplifier, and oscilloscope. Experiments with the model led to a study of the general laws of propagation of elastic waves in media with nonhomogeneities of a "structural" nature, which means that the region under study includes a great number of separate nonhomogeneities. The model used was an example of an artificial medium of this type. Riznichenko noted that natural media of a similar type are often encountered in seismometry, e.g., sand in a weathering zone.

Several problems in the propagation of elastic waves in media with structural nonhomogeneities are discussed (only longitudinal waves are used in the discussion, but the same considerations apply to transverse waves). A differentiation is made between discrete discontinuous media consisting of separate particles bonded by elastic forces and heterogeneous media, i.e., continuous nonhomogeneous media with nonhomogeneities of a structural nature. Formulas were derived for the velocities of low-frequency waves in a little chain made up of masses and elasticities (the simplest discrete medium) and in a series of plane-parallel layers having different properties (a simple case of a heterogeneous medium).

A number of examples are given to illustrate the applicability of the velocity formulas derived to the determination of the order of possible values for seismic velocities in certain real media (dry quartz sand, sand saturated with water, quartz suspension in water, and loose snow). The usual formula of geometric seismics for the "average velocity" is not applicable in these cases. Observations of the waves in the network model indicated that the discreteness (fracturing, etc.) and heterogeneity (nonhomogeneity of a structural nature) of certain real geological media cause a number of phenomena which are usually related to the nonideal elasticity of the medium (plasticity, viscosity, and aftereffect). These phenomena include: decreasing sharpness of the wave front as the wave moves further from the place of explosion or impact; the relative increase of the basic period of the wave, which is very noticeable at short distances and less noticeable at great distances; and stabilization of the form of vibrations at great distances. These and other similar phenomena should not be ascribed solely to nonideal elasticity. The case of a stratified heterogeneous medium considered in the discussion can be applied directly to certain real thinly-stratified media (slates, Flysch strata, etc., for example).

In a subsequent article, Riznichenko discusses seismic quasi-anisotrophy (8). The main points of Riznichenko's paper follow: Geological media, in particular layers of sedimentary formations, are often stratified. Under certain conditions the alternation of heterogeneous isotropic layers may cause phenomena similar to the anisotropic effect. These stratified isotropic media can be considered quasi-anisotropic in a certain sense. The velocity of propagation of elastic waves in such media is of prime importance for seismometry. Manifestations of "anisotropy" (quasi-anisotropy) in seismics are classified. The elastic properties of a quasi-anisotropic stratified medium consisting of isotropic solid layers are then discussed theoretically. The elasticities and propagation velocities were calculated for transverse elastic waves in this medium for directions across and along the layers.

Three basic forms of quasi-anisotropy were found: (1) of the effective and average velocities, (2) of the layer and boundary velocities, and (3) of the velocities of long waves propagated across and along the layers. Numerical examples are given for the case of layers with very different properties and for the case of layers having similar properties. The first case approximates those conditions (interbedding of carbonaceous limestone and clays) encountered in seismic prospecting in the Podmoskov'ye region while the second approximates those found on the Apsheron Peninsula and several other oil-bearing sandy-clayey regions of southern USSR.

Berzon made a study (9) of the form of the indicatrices of average velocities for isotropic stratified media and a comparison of them with the indicatrices of velocities for homogeneous anistropic media and showed that the question of homogeneous and anisotropic or stratified and isotropic medium can be answered by the form of the indicatrices obtained in parametric measurements of the velocities. Berzon found that a method of field observations must be used in which the differences between the indicatrices corresponding to anisotropic and stratified media will be quite apparent; inasmuch as the form of the indicatrices changes substantially in stratified media for different orientations of the line of observations with respect to the line of stratification and for different distances from the explosion point, the velocities should be measured along different orientations. The points of observations on these lines should be chosen so that part of the indicatrices of velocities would be obtained for a large range of values of the angle formed by the line connecting the explosion point and the receiver of the vibrations with the axis perpendicular to the line of stratification.

Berzon noted that a comparison of the indicatrices obtained by this method with the theoretical indicatrices calculated for stratified and anisotropic media will determine the anisotropy or stratification of the medium under study with respect to velocities. Homogeneous anisotropic media and stratified isotropic media, which contain comparatively thin layers of increased velocities, can be distinguished easily by the form of the observed indicatrices of velocities. Thus, Berzon concludes, parametric measurements can be used to check the hypothesis, often mentioned in seismic literature, that thin layers of increased velocities are present in strata of sedimentary deposits.

Berzon reports that during the 1946 - 1947 field season, parametric measurements of velocities in various stratified media were conducted by the Department of Experimental Seismology of the Geophysics Institute, Academy of Sciences USSR; indicatrices were obtained which demonstrated that thin layers with increased velocities are actually present in these media. The width of these layers was frequently only 10-20 centimeters. Experiments in the study of the velocity structure of various rocks are being continued at present. The results of these studies will be presented in a special work.

In a later report (10), Berzon discusses the interpretation of hodographs of Mintrop (refracted) waves for a refracting boundary of arbitrary form. He notes that an accurate solution of the spatial problem of interpreting hodographs of refracted waves, i.e., determining the refracting boundary from the given hodograph, has been obtained only for the case of a flat boundary for given constant speeds V_1 and V_2 in the covering medium and in the refracting layer. Berzon details a method for determining the refracting boundary of arbitrary form given arbitrary laws for the variation of velocities V_1 and V_2, assuming that the wave in the second medium slides along the refracting boundary.

An article by A. S. Antsyferov (11) discusses the instrumentation used in seismic prospecting

The Gravitational Method

In a continuation of a work relating to gravitational prospecting, B. A. Andreyev (12) details a method for calculating potential fields in the lower halfspace, including the potential source. The paper can be summarized as follows: The solution of the problem is obtained in the form of a Fourier series, the terms of which are calculated successively in integral form. The method can be used to solve a number of problems connected with the processing and interpretation of geophysical data. This applies not only to gravitational and magnetic surveys but to other quantities characterizing stationary or quasi-stationary processes studied in geophysics. Thus, it may be possible to apply this method to electrical prospecting, thermal prospecting, gas surveying, etc. /The term "potential" as used in this article applies with equal force to a magnetic, electric, or gravitational field./

The use of diagrams characterizing the spatial distribution of potential derivatives has been hindered because of the difficulties involved in calculating these derivatives, particularly in the lower space. The use of this method will eliminate this difficulty. Proper utilization of these diagrams will determine the size and shape of the disturbing masses. Actually, the problem reduces to the determination of the positions of special "singular" points of the potential function under consideration. This disposition of points is in each practical case connected with the configuration of the geological object. The surfaces of geological bodies are usually boundaries of the physical properties of rocks and usually do not have continuous curvature but have discontinuity points and other irregularities.

In all these cases, the special singular points of the potential function under study must be located on the surface of these geological bodies. For bodies which are close in form to sloping strata or which have a flat upper edge and sharp sides, the closest special singular points of the potential will be found on the upper surface of these bodies. The depth of this surface can be determined by studying the convergence abscissas of a series of the type: sum $U(x',h) = \bar{U}(x',0)$ plus sum $i_k U(x',h)$. The structural elements of the crystal foundation of the Russian platform, for which sharply sloping boundaries separating the physical properties in the pre-Cambrian rock stratum are characteristic, can be used as an example. The top of this stratum is usually bounded by an almost horizontal surface of ancient erosion shear. The depth of this surface can be determined by studying the series mentioned for the magnetic and gravitational anomalies of the platform inasmuch as the latter are connected with the internal structure of the crystal foundation.

Such calculations were made for a number of regions of the platform for which deep drilling data was available. In all cases, the results of this type of interpretation corresponded satisfactorily with the factual material for the depth of the top of the foundation. Similar calculations with good results were made for several ore anomalies of moderate size. When certain conditions are observed, this method can also be used for processing the results of aerial magnetic surveys. The character of anomalies on the earth's surface can be judged by the character of the corresponding anomalies registered from an airplane. Thus, in certain cases it is possible to use data from aerial magnetic surveys to detail magnetic maps compiled from the comparatively sparse network of surface magnetic observations. The method also might possibly be used for planning an underground geophysical survey from the results of surface observations.

In another article on the gravitational method, V. A. Magnitskiy (13) states that the wide introduction of gravimeters into the practice of gravimetric surveys has increased the accuracy of the surveys and the network of points and thus has increased the potentialities of the gravitational method of geological prospecting. He notes that it also has raised the requirements for the processing of gravimetric data used in geological interpretation. Magnitskiy reports that the problem of classifying local and regional gravitational anomalies has been given increasing attention recently and refers to a recent discussion of strict methods of classification in general and their physical meaning in a work by A. N. Tikhonov and Yu. D. Bulanzhe. Magnitskiy discusses one special case, i.e., that of the method of obtaining a regional gravitational field by reducing the observed anomalies to a remote external level surface. The method devised by Magnitskiy was applied for the Samarskaya Luka region and for part of the right shore of the Volga near Saratov, as follows:

The previous maps compiled from variometric surveys of the Samarskaya Luka region were reworked by Engineer L. P. Bobrov because they did not give full consideration to the topography of the region and thus the data could not be wholly related to the Bug anomalies. The map compiled by Bobrov thus did not have that direct connection with the topography of the region which was characteristic of earlier maps, but was connected mainly with the tectonics of the region, the structure of the crystallic foundation, and the structure of the deeper zones. Bobrov's map compared well with one compiled by Ye. N. Permyakov for the Schwagerina beds, thus indicating the correctness of the method used to classify the fields.

A third article (14) relating to gravitational prospecting is a theoretical study of the gravitational field created by an infinite number of parallel circular cylinders equidistant from each other and at an equal depth under the plane of observations.

Thermal Methods

In the field of geothermal studies, the thermal anomalies of the Ishimbay deposits were investigated by S. S. Kovner (15). His report contains the following information:

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The Ishimbay deposit in most cases may be considered from the thermal standpoint as made up of three or four homogeneous layers; e.g., the Ufa red soil, the Kungur deposits, and the Artinsk limestone. In the case of a consistent folding of an anticlinal nature in the Kungur and Artinsk layers (which occurs in a number of Ishimbay masses), and also for cases of reverse stratification when the convexity of the Kungar corresponds to the concavity of the Artinsk limestones, the temperature measured at a depth of about 100 meters above the top of the submerged mass must be greater than the temperature measured over the bottom of the same mass. The temperature difference over the top and over the bottom of the submerged mass creates a local thermal anomaly. This anomaly is due to the totality of the configurations of both layers, the Kungur and the Artinsk limestones, and is called a primary thermal anomaly.

Kovner had previously devised a method for calculating these anomalies by numerical integration of the differential equations for a problem which took into consideration the complex configuration of the internal boundaries and the continuity of temperatures and heat flow. The calculations showed that the magnitude of the anomalies was such that they would be discovered if the thermometric observations were accurate to 0.1 degree. This led to a decision to conduct thermometric measurements in this region; these were carried out by a number of small expeditions during the summers of 1944, 1945, 1946, and 1947. The anomalies predicted from the calculations were actually found. Assmann thermometers were used for the measurements; these were put in a protective metal case filled with a poor heat conductor.

Special experiments by N. K. Kukharenko and Yu. A. Gulin determined the length of time which the case should be left in the drill hole and eliminated the influence of temperature variations due to the lifting and lowering of the cases. The measurements were usually made at depths of 100 and 200 meters and sometimes at 300 meters and 50 meters. The measurements at 50 to 100 meters were the most reliable. The thermal conditions of the following regions were studied: the southern mass, western mass, eastern mass, Kuz'minovskiy mass, and the Kinzebulatovo, Kusyapkulovo, Termen'-Yelga, Salikhovo, Yuzhnaya Kashkara, Allakayevo, and Yar Bishkadak masses. Measurements were made in a total of 109 drill holes. This region thus has been more thoroughly studied from the geothermal standpoint than any other in the Soviet Union.

The methods of mathematical physics, in particular the methods of numerical integration of a system of differential equations of heat conductivity, make it possible to predetermine geophysical fields, in this case thermal fields. This is the basis for the thermal method of prospecting for submerged structures. The studies also showed that primary thermal anomalies at 100-meter depths are objects worthy of careful study since they may be indicators of oil-bearing structures in a number of cases. Some of the most prominent specialists in the field of geological and geophysical prospecting aided in the measurements: Yu. A. Gulin, N. K. Kukharenko, A. A. Trofimuk, S. I. Kuvykin, P. A. Pospelov, V. I. Kharkevich, V. D. Sapozhnikov, and A. I. Khramiy.

Belyakov's study (16) of a possible dependency between geoisotherms and the pre-Cambrian bed of the Russian platform required the collection and analysis of thermometric data from deep wells of the Middle Volga and the land on the left bank of the Volga. It would have been desirable, Belyakov notes, to have geothermal measurements obtained by mercury thermometers to give greater accuracy in absolute values, but such measurements are not available for the Middle Volga region. The investigation proceeded as follows:

Two regions were taken for study: Samarskaya Luka and Buguruslan, located 200-270 kilometers apart. Samarskaya Luka is in the raised zone of the crystal foundation while Buguruslan is in the depression zone. The crystal bed in the Samarskaya Luka region is 1,500-1,600 meters deep; dropping as it moves east, it lies 3,000 meters deep at Buguruslan. Results of measurements showed that the geoisotherm 25 degrees centigrade passed through 1,000-meter depths in the Samarskaya Luka region and 1,500-meter depths in the Buguruslan region. Thus, a definite connection was found between geoisotherms and the structure of the Russian platform at these locations. The geoisotherm 25 degrees centigrade, as it were, repeats the contour of the crystal foundation. Thus, Belyakov found that the configuration of the surface and the depth at which the pre-Cambrian foundation lies can be forecast in a rough manner by temperature measurements in wells which do not reach the crystal bed.

Miscellaneous

A new hydrochemical method of prospecting for oil and gas deposits has been proposed by M. S. Kaveyev, collaborator of the Geological Institute of the Kazan Affiliate, Academy of Sciences USSR (17). According to Kaveyev's analyses, ground waters close to oil deposits change their usual composition. For example, the waters of the Tatar ASSR usually have a p^H of 7 and a ratio of magnesium to calcium content of about one. In areas of oil-bearing deposits, this ratio changes sharply to 1.8, 2.5, and higher. At the same time, the p^H of the water deviates from 7 either up or down. Kaveyev notes that his observations related to a particular region, and that the changes might be different in other regions. However, he asserts that this change in the ratio of the content of alkali earth elements and the p^H of the water, could be studied in other regions and used along with other factors as an indication of oil and underground gas.

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